DECISION SCIENCE INC.

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TECHNICAL REPORT

RESEARCH ON REMOTELY PILOTED VEHICLES CONTROLS AND DISPLAYS

15 SEPTEMBER 1972

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15 SEPTEMBER 1972

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13. ABSTRACT

Various missions for Remotely Piloted Vehicles were considered. Primary emphasis was then placed on strike and reconnaissance missions. A review of the literature and available current knowledge on the design of appropriate displays and controls revealed crucial questions which remain unanswered (relating to the nature of displays and control as well as the specific dependency of the display/control situation on the background of knowledge and experience of the pilot). Clearly, the nature of selection and training of future RPV pilots hinges upon such knowledge.

Experiments were devised to address these questions in a quantitative manner. The first experiment is now under way using subjects drawn from four populations: qualified Navy fighter pilots, radio controlled model airplane pilots, nonpilot engineers with driving experience, and nonpilot nonengineers with driving experience. Eight different display/control situations are being examined for the strike mission: all combinations of inside-out versus outside-in attitude display, predictive versus nonpredictive attitude display and attitude versus attitude rate control. The second experiment will introduce greater realism and include pilot control of the television viewing angle and magnification. Analysis of the data resulting from these experiments should provide significant findings in terms of the principles of display and control design for Remotely Piloted Vehicles.

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TECHNICAL PROBLEM

The intent of this investigation is to definitize principles pertinent to the design of displays and controls for the Remotely Piloted Vehicles which will reach operational status in the 1980-1985 time frame. After considering a wide variety of alternatives prospective missions for such airborne RPV's primary attention was restricted to strike and reconnaissance missions with deferred attention being given to air superiority and other missions. The possibility of simultaneously controlling a number of RPV's and the use of special weapons was also deferred to later consideration.

It was recognized that even this restricted variety of missions might call for diverse aircraft types ranging from conventional subsonic jet driven drones through vertical takeoff aircraft (helicopters and autogyros), and even to include small propeller driven aircraft such as those ordinarily flown as radio controlled sport models. Further, personnel to be charged with the responsibility of controlling RPV missions may range from those essentially naive in aerodynamics and flight control to those fully qualified in attack piloting. The problem is to identify the relative worth of various classes of pilots as each of these faces the best display/control situation for that class. This knowledge will provide important design information as well as a background useful for improved personnel selection and

training for future RPV pilots.

More precisely, the task is to design experiments which will elicit empirical evidence pertinent to the required decisions which must be made in the near future with respect to the design of the man-machine interface, the selection and training of personnel, and the kinds of mission capability which may be realized by Remotely Piloted Vehicles in the 1980-1985 time frame.

GENERAL METHODOLOGY

A survey of the literature revealed a great number of technical papers pertinent to the above referenced problem. These papers were acquired, reviewed and classified with respect to the kind of information they contain. Certain of these papers were annotated in order to summarize the most important findings of previous investigators as these bear upon display and control design for future Remotely Piloted Vehicles.

A wide variety of alternative missions for RPV's were then structured in some detail, this in the light of the anticipated state of the art and military requirements of the 1980-1985 time frame. A presentation of these findings before Dr. Martin A. Tolcott, Scientific Officer under this contract, and other personnel of the Office of Naval Research resulted in top priority being placed on the strike mission with secondary priority being devoted to the reconnaissance mission. For the purpose of this study the air superiority mission was considered to be of far less importance.

A review of the anticipated technology revealed an estimate of the degree to which such future RPV's will require the human operator and in what capacity. For example, it was learned that navigational capability will most likely be adequate without human intervention. In contrast, target detection, classification, and designation are not likely to be automated by that time. This is particularly

true in view of the conflicting computational and cost requirements which will be placed on RPV's. Even with extensive computational capability available at the remote control station, targeting hinges upon the reliability of the high data rate communication link. There is reason to believe that the human operator will serve as the most efficient pattern recognition filter in this regard, especially when the video presentation is degraded by unseen circumstance and enemy action.

It is also unlikely to completely automate control of the final maneuver. A wide variety of conditions may prevail in the immediate locale of the target. The most suitable trajectory will depend upon these conditions as sensed and perceived. Here again the human operator is of great value. To illustrate, a "horizontal approach" may be most suitable for attack of a large ship but this would be inappropriate in addressing a reveted target. Here, a "pop-up" maneuver of a particular kind is called for. Further, an effective RPV pilot will take into account enemy activity as noted during performance of the final maneuver. The considerable variety of RPV dynamics raises the question of human control of vehicles having such different handling quality. RPV's may fly according to preprogrammed instruction but will most certainly have an override capability given to the monitoring human operator. But for override to be effective, there is the requirement that the pilot

can manually control the vehicle; for example, an RPV may fly passively upon entry into enemy territory, being programmed to emit energy for the first time when it reaches the proximity of the target. At this point, the human operator may command a particular frame rate, individual video frames, or continuous video depending upon his view of the terrain and target. Unexpected circumstance, the appearance of certain targets of opportunity, or unreliability of the weapon system may call for direct manual flight control to complete the mission. In addition, the human operator may have direct control over the TV or FLIR sensor. Success of the mission may well hinge upon the proper execution of this control and coupling this to flight control. Needless to say, the human ooerator will be a particular asset in situations which call for multiple RPV operation in consort or serial modes. Details in this regard are deferred from present consideration.

Investigation of the specific capability of the human operator under this variety of circumstance calls for an experimental investigation thus two experiments were conceived, designed and are currently being conducted in order to gain curcial information with respect to the capability of different classes of pilots as each faces its best display control situation.

TECHNICAL RESULTS

The first of these experiments presents eight different display/control situations to four classes of pilot-subjects. Specifically, these situations include inside-out versus outside-in attitude display, predictive versus nonpredictive attitude display, and attitude control versus attitude rate control. Note that all of these situations concern attitude which is considered to be the critical variable of direct manual control. Proper attitude control in this regard yields desired control of altitude, airspeed and ground track, and the avoidance of stall, missing target detection, and placing undesirable forces upon the airframe. It is recognized that stability augmentation and additional automated flight control can reduce the need for close control. But to estimate the worth in this regard, it is essential to begin with an investigation of the human operator in full close control.

The four classes of subjects span the gamut of experience and knowledge of pertinent psychomotor skills. Eight subjects are drawn from the population of individuals holding extensive driving experience but without significant knowledge of aerodynamcis and flight control; eight subjects have engineering background pertinent to flight control and are experienced drivers but have no actual piloting experience; eight subjects are radio controlled model aircraft pilots; and eight subjects are fully qualified Naval fighter

pilots. Obviously, individuals in these last two classes hold knowledge of aerodynamic principles as background to their flight control. All are right handed male adults. The specific intent of this experiment is to identify the degree to which mission performance hinges upon the background of experience and knowledge of the subject and the display/control situation he faces. It might be that piloting experience should be prerequisite for future RPV pilots but it might also be that RPV pilots may be selected and trained for that task without the additional cost and time required for gaining other flight control experience.

Each subject will be interrogated concerning his background of pertinent knowledge and experience, given a shortened version of the Witkin Embedded Figures Test and a brief examination which measures his anxiety in terms of the Kugelmass Worrying Scale. These tests indicate different aspects of cognitive function and emotional attitude pertinent to the kind of psychomotor task required in RPV mission control. The subject is then requested to operate a simulated vehicle which moves in a two-dimensional frictionless inertial space. His discrete controls permit additive degrees of acceleration and rotation. He is requested to control his vehicle in such a way that it will collide with another simulated vehicle which is seen to move across the screen at a constant speed. The time required for this is measured. Here the intent is to present all subjects with

a psychomotor task none are familiar with, thus permitting some individual normalization across the classes of subjects. At their option the subjects are then permitted to engage in a more complex simulation called "space war" wherein these same vehicles can be individually driven by different operators who can release projectiles at their own discretion.

The subjects are then briefed on the scenario of the RPV mission which, in the case of the first experiment is a simple strike mission always of about the same difficulty. The RPV is launched from a mother aircraft at 2000 feet over friendly territory. It gains speed and must descend to its operational altitude. At lower altitude, it encounters atmospheric turbulence. Upon entering enemy territory the attitude display is degraded by simulated ECM. The pilot monitors the movement of the RPV in terms of a pen which traces the ground track over the planned scenario (which has numerical indications of desired altitude and airspeed at critical times). The attitude and target (appearing as a 500 ft. diameter circle seen in perspective) is shown on a CRT. Pointer-on-scale instruments indicate present altitude and airspeed. Controls include a two-axis stick coupled to attitude or attitude rate, a switch which actuates a 10-fold expansion of the altitude scale, another switch which is depressed to indicate sighting of the target and a foot switch which is

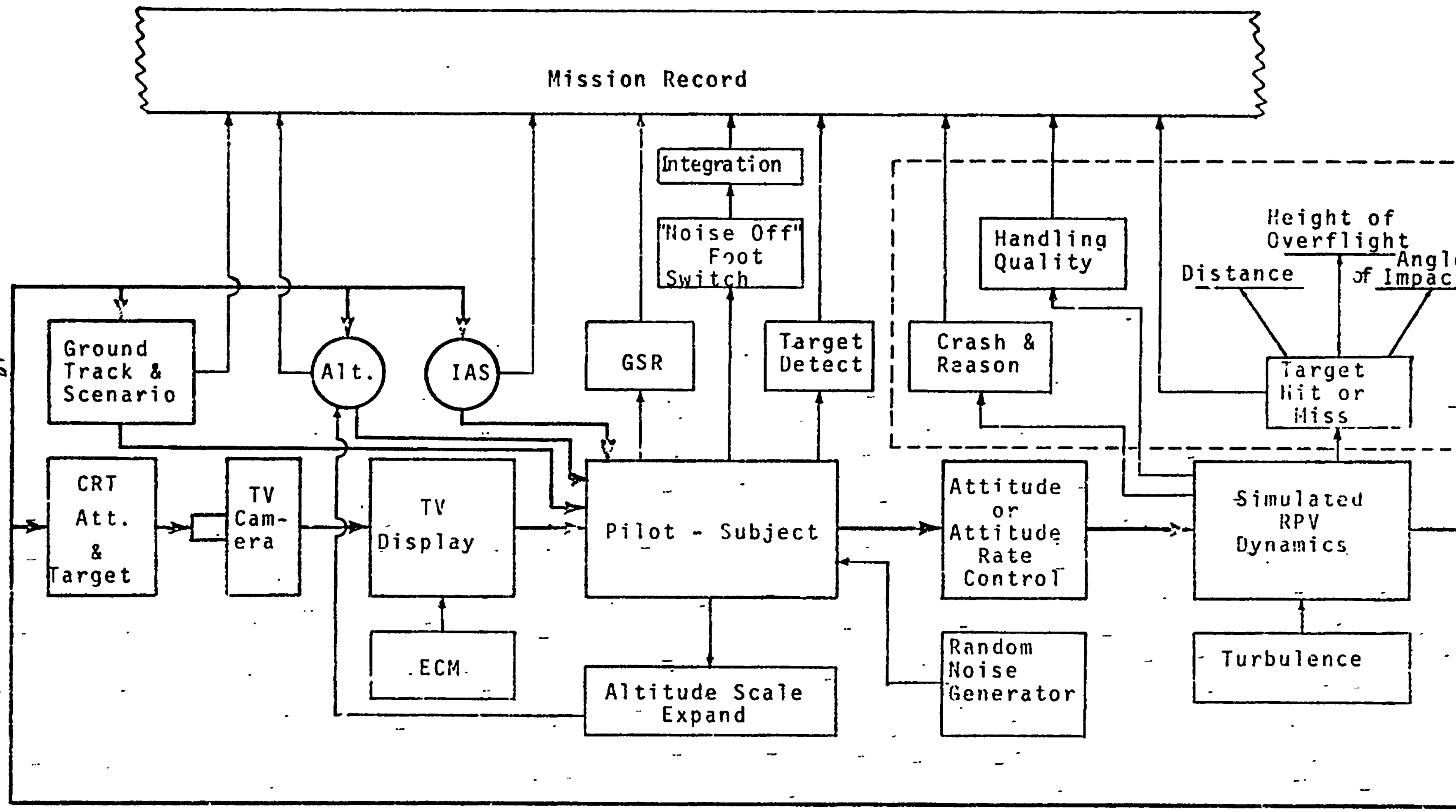
depressed to eliminate the sound of a randomly activated buzzer (this being the secondary task). Electrodes are placed on the left hand of the subject so as to monitor his autonomic nervous response. After a brief demonstration, with and without ECM (imposed snow on the CRT), the pilot is informed that he must limit both pitch and role to ± 30 degrees, that stall speed is 180 knots with the dangerous stall range shown on the airspeed indicator and that excessive g's may overstress the airframe. All instructions are routinely administered and reproducible.

During the performance a paper tape record is made of the x-y coordinates of the aircraft, its airspeed, altitude, the subjects' Galvanic Skin Response, the probability of mission success as computed in terms of the probability of target detection, of losing the aircraft to enemy ground fire and of hitting the ground through the effects of turbulence, a measure of the handling quality of the vehicle, and the cross-track error, each of these being functions of time. At the end of each simulated mission, the computer prints out the initial conditions, the time the target first actually appeared on the screen, the time the target was reported by the subject and the nature of the impact in terms of hit or miss. (If a hit, the impact angle is measured. If a miss, then the distance from the target or the height of the overflight is noted.) If the aircraft failed to reach the target area, the computer prints out that a crash occurred and the reason for that failure.

Score is also kept of the total time the randomly presented sound is left on thus indicating an inverse measure of the degree of absorbtion in the primary task and the subjects' capacity. In all cases the simulated RPV will have dynamic performance typical of a subsonic jet driven drone such as the Firebee.

Figure 1 indicates the experimental setup. Computer programming in this regard is now practically completed. Preliminary experiments are being performed to determine the optimal prediction time with respect to both pitch and role in terms of minimized cross-track error under turbulence. The first scheduled subjects will begin the experiment on September 16. It is estimated that at least three weeks will be required for completion of this experiment. Upon completion of the experiment the data acquired will be submitted to conventional factor analysis and other statistical procedures.

A second experiment has been devised to broaden the investigation with respect to types of RPV, classes of operating personnel, and display/control capability. Specifically, three different kinds of aircraft will be simulated in this experiment: the same conventional subsonic jet driven drone, a vertical takeoff RPV (replicating a helicopter or autogyro) and a fixed wing propeller driven aircraft (having the dynamics of a conventional radio controlled model aircraft). It is recognized that still other kinds of vehicles may be required for RPV missions; however,



Mission Record
Integration
"Noise Off" Foot Switch
Handling Quality
Height of Overflight
Distance
Angle of Impact
Ground Track & Scenario
Alt.
IAS
GSR
Target Detect
Crash & Reason
Target Hit or Miss
CRT Att. & Target
TV Camera
TV Display
Pilot - Subject
Attitude or Attitude Rate Control
Simulated RPV Dynamics
ECM
Altitude Scale Expand
Random Noise Generator
Turbulence

FIGURE 1

consideration of these types is deferred for future consideration. The same classes of pilot subjects (and indeed in some cases the same subjects) will be used in the second experiment but with the addition of a class of subjects: qualified Navy attack pilots. The subject will have an opportunity to perform a far more realistic simulated strike mission with some additional reconnaissance requirement. The same measures of performance will be used. The display, however, will be generated from a color motion picture taken under prior Navy authorization. This presents a low altitude, high speed view of diverse terrain which includes prespecified targets. The subject will see a black and white televisual presentation of a portion of that motion picture image in accordance with the pointing angle and field of view of the television camera, presumably mounted in the nose of the aircraft. The speed of that aircraft (of the projector) is a reflection of his throttle position and the dynamics of the vehicle. His task is to control both the aircraft and the camera. Two alternatives are presented in this regard. At the same time, he is instructed to minimize emitted energy, thus he controls the frame rate of the TV camera. Lastly, the camera can be locked to the airframe or mounted on a stable platform, his view being quite different in these regards. The pilot-subject will be prebriefed regarding targets of greater importance than that assigned to this mission; thus, he may

choose to divert the RPV to targets of opportunity should they appear. Upon designating a target, the camera display is replaced by the symbolic display on a CRT as used in the first experiment. Figure 2 indicates some features of this experiment. It is estimated that this experiment will be performed in November and December.

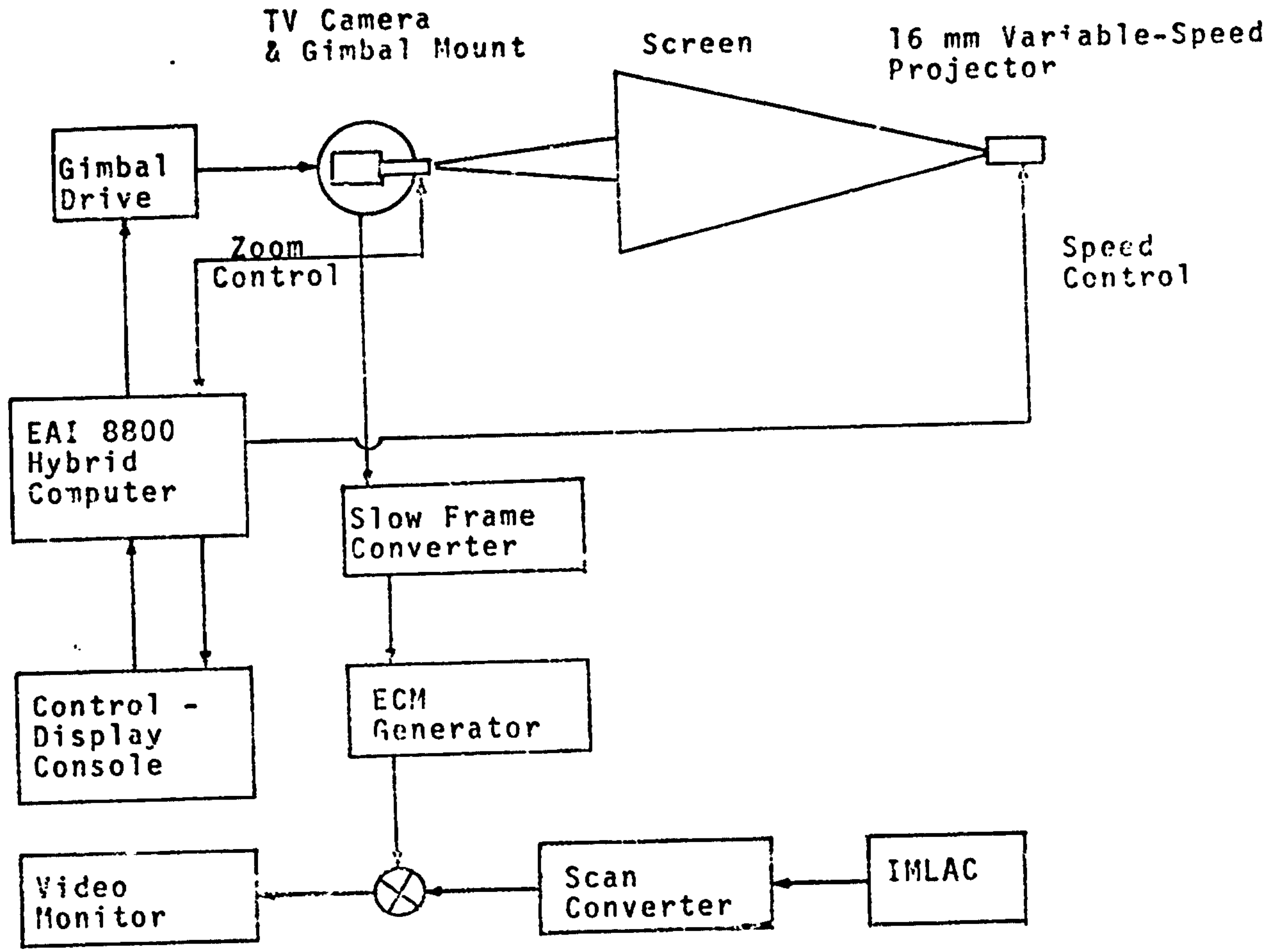

TV Camera
& Gimbal Mount
Screen
16 mm Variable-Speed
Projector
Gimbal
Drive
Zoom
Control
Speed
Control
EAI 8800
Hybrid
Computer
Slow Frame
Converter
Control -
Display
Console
ECM
Generator
Video
Monitor
Scan
Converter
IMLAC

FIGURE 2

DOD IMPLICATIONS

RPV's offer considerable advantage over fighter aircraft for technical, tactical and political reasons. They can reduce operational costs, can perform higher g maneuvers, can be assigned to higher risk missions, and prevent enemy acquisition of pilot-hostages. But to realize these benefits the RPV must be designed to properly couple with the human operator for whatever class of personnel may be appropriate for selection and training. Further this training should be at less cost than that required for manned aircraft.

RPV's may address a wide variety of missions and be launched from aircraft, ships, or ground stations. The remote control sites may be at these stations or close to the intended mission objective. Here is a weapon system which requires unified action across the various commands and military services. Determination of principles of display and control design for this weapon system should be of immediate concern to the Department of Defense.

IMPLICATIONS FOR FUTURE RESEARCH

The work performed under this contract is but an essential initial step. A number of important questions remain to be answered. There is need to determine the most suitable level of autopilot capability for various missions and ways in which the human operator can properly use this capability; there is need to examine alternative modes for multiple RPV control. The relative worth of FLIR and/or TV must be determined, especially in view of space, weight and cost constraints which may limit the sensory suit. It is worthwhile to examine alternative visual displays as these can reduce navigational error, provide enhanced targeting, improve flight control through time compression or expansion (such as the use of predictive control) and so forth. It is also important to examine the degree to which estimates of mission success benefit the mission through display of these indicators to the pilot, various modes to improve mission control through flight director displays, and ways to improve recovery. We need to improve our knowledge of the worth of different amounts and kinds of prebriefing and to examine the use of such simulations as these experiments for the purpose of training personnel. A more detailed indication of this work is contained in the unsolicited proposal, DSI-11890.

TECHNICAL REPORT SUMMARY

Technical problems relating to the man/machine interface of Remotely Piloted Vehicles of the 1980-1985 time frame were identified in view of the anticipated state of the art, military situation, types of missions, availability of personnel, and so forth. A literature review was followed by mission analysis and priority rating with only strike and reconnaissance being of immediate concern. Experiments were then designed intended to address crucial problems pertinent to principles for the design of displays and controls for RPVs. The first of these experiments pertains to the frame of reference and temporal reference for attitude display as well as the mode of attitude control. The second experiment will concern control of the TV sensor in terms of field of view, stability requirement, and minimum energy emission from the RPV. The study should be of particular interest to the various commands and military services in that RPV missions support the responsibility of these agencies. Further technical questions have been identified and can be treated in a follow-on study.

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APPENDIX

FURTHER INVESTIGATION INTO THE PRINCIPLES OF DISPLAY AND CONTROL DESIGN FOR REMOTELY PILOTED VEHICLES

DSI-11890

Submitted To:

ENGINEERING PSYCHOLOGY BRANCH
OFFICF OF NAVAL RESEARCH
WASHINGTON, D. C.

September, 1972

INTRODUCTION

Contract No. N00014-72-C-0196 authorized Decision Science, Inc. to investigate principles of display and control design for Remotely Piloted Vehicles. Work performed under this contract is indicated in the technical report which forms an Appendix to this proposal.

During the course of this work it has become evident that great utility will be gained through the use of Remotely Piloted Vehicles only if these are properly equipped in terms of the man-machine interface. Further, personnel may be trained to perform RPV missions at far less cost than that required for their control of manned combat aircraft. The experiments being performed under the above referenced contract examine the adequacy of a number of different display/control situations as these are faced by different classes of subjects in the performance of strike missions. Some consideration is also given to reconnaissance missions.

But there is need for further knowledge. Thus far, only three types of RPV's have been simulated: a typical subsonic jet driven RPV (such as the Firebee), vertical takeoff aircraft (helicopters and autogyros), and fixed wing propeller driven model aircraft (such as those usually used for radio controlled sport flying). Clearly, it is important to also consider aircraft of supersonic capability

and those which offer extensive glide, variable configuration, rocket assist, and so forth. It is also important to investigate the ways in which the RPV pilot can take best advantage of various levels of automated flight control, these ranging from simple stability augmentation through the usual autopilot capability and on to the more sophisticated tactical autopilot capability which might well be available in the 1980-1985 time frame.

There is also need to investigate the potential benefits to be gained by providing the pilot with a composite view of his scenario and immediate prospect. A number of possibilities are available in this regard, including the superposition of conventional displays, the introduction of intentional distortion such as duplex fields of view, and so forth. Such displays might facilitate the reduction of navigational error, especially in situations wherein automatic navigation accuracy is being degraded by the enemy. It might also be worthwhile to investigate the potential value of displaying the probability of mission success in terms of the intended target (so that the pilot can perform effective tradeoff of that target versus targets of opportunity). Various means for time compression and expansion might also benefit his performance.

Certainly multiple RPVs will be used in future missions. The question remains unanswered as to how best to control these vehicles in consort or serial operations. Should a single remote pilot control a number of RPVs through their entire mission or should there be specialized pilots for different phases of the mission with "hand-over" as required? For

example, a particular human operator might be in control of final maneuvers while another might be reserved for control against airborne weapons which attack the RPV. Perhaps a single operator can provide midcourse guidance for a number of RPVs on similar missions. It is also worthwhile to consider alternative sensory capabilities including FLIR and/or TV, especially under all weather (with enemy ECM) conditions. Lastly, some consideration may be given to the use of the simulation capability as provided in the above referenced experiments as a basis for the training of naive subjects to become qualified RPV pilots.

The Statement of Work and Statement of Cost which follow this brief discussion are intended to make this proposal concrete.

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DSI-11890

STATEMENT OF WORK

Examine the findings of work already performed under Contract N00014-C-72-0196 and other current research in order to identify additional technical problems which must be resolved in order to complete the definition of principles of display and control design for Remotely Piloted Vehicles. In this regard take into account estimates of the state of the art (with particular emphasis on computer technology and communication requirement in the face of ECM), the anticipated military situation and kinds of missions which might be called for, the availability of personnel of different knowledge and experience, and so forth. Devise various displays and controls which contrast alternative positions with respect to the above referenced principles, and on this basis, devise experiments which serve to overcome the uncertainty. In particular, consider the problems of multiple RPV control, use of different levels of autopilot, composite fields of view for improved targeting and the reduction of navigational error, time scaling of displays and control, the presentation of estimated values for the degree of success to aid the mission performance, the use of alternative sensors (FLIR and/or TV), displays suitable for improved recovery, and the possibility of using such simulations for training and evaluation purposes. Perform

suitable data reduction and analysis and, on the basis of the findings, prepare recommendations with respect to principles of display and control design with illustrations as appear appropriate.

Specifically, the following tasks will be performed:

Task 1 - Review the work performed and findings derived under Contract N00014-C-72-0196. Identify any unresolved uncertainties with respect to attitude display and control in the manual mode as well as TV monitor mounting exercise and field of view control.

Task 2 - Identify crucial questions pertinent to multiple RPV control, use of different levels of auto-pilot, composite fields of view for improved targeting and the reduction of navigational error, time scaling of displays and control, the presentation of estimated values for the degree of success to aid the mission performance, the use of alternative sensors (FLIR and/or TV), displays suitable for improved recovery, and the possibility of using such simulations for training and evaluation purposes; this within the priority weighting and available time constraints imposed by the Contract Monitor.

Task 3 - Prepare equipment and computer programs suitable for conduct of such experiments.

Task 4 - Conduct experiments using volunteer subjects of particular kinds of knowledge and experience as appropriate to the experiment design. Perform

data reduction analysis and develop the findings on this basis.

Task 5 - Prepare recommendations pertinent to principles of display and control design, illustrating these with particular examples of displays and controls so as to benefit the performance of Remotely Piloted Vehicles of the 1980-1985 time frame.

Task 6 - Prepare and submit quarterly progress reports and a final report which summarizes the work performed over this one-year contract effort. This final report to include specific recommendations which should lead to specifications for the procurement of suitable displays and controls for Remotely Piloted Vehicles.

The above tasks are to be conducted under the responsibility of Decision Science, Inc. with the support of Teledyne Ryan Aeronautical Company, the work in this regard is to be performed in a 45 to 35 ratio respectively. It is assumed that, as in the past, the local military will furnish pilot subjects as may be required at no cost to these contractors.

PROPOSED SCHEDULE OF PERFORMANCE